Solar wind properties from SOHO-Ulysses observations

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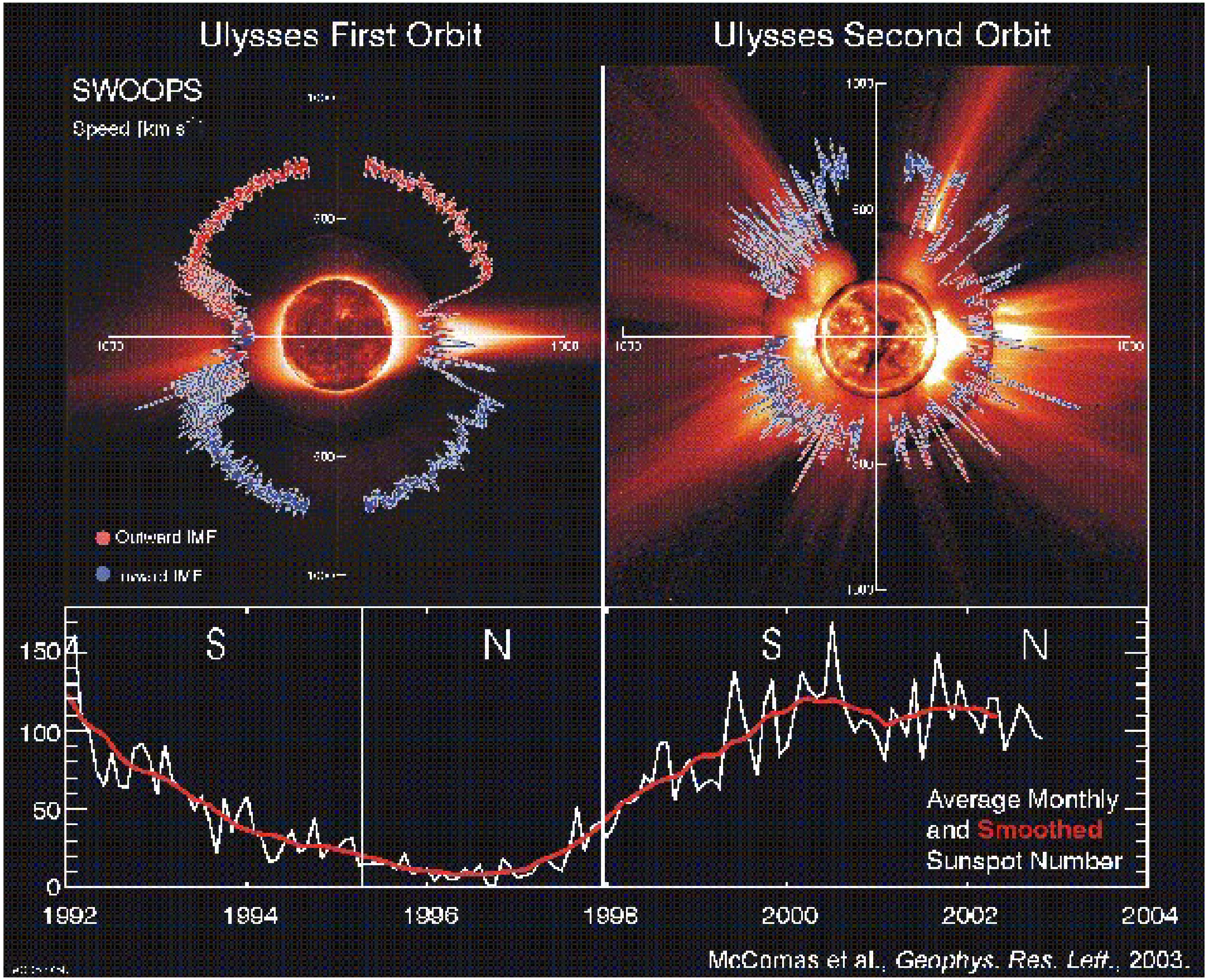
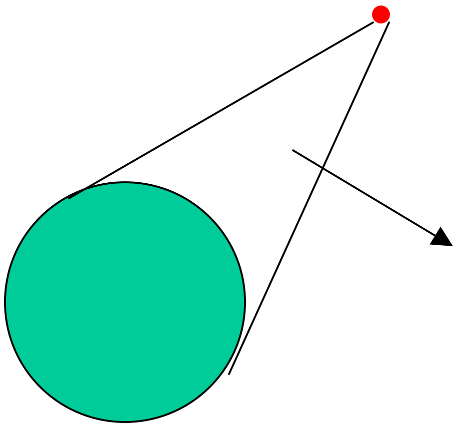
Wind speed vs. latitude from Ulysses observations



What we knew before SOHO

- Coronal holes → Fast wind
- Low latitude → Slow wind
- Interplanetary scintillation measurements
- Questions: what happens in the first few solar radii?
- Where (in CH) does fast wind originate?
- Where does slow wind originate?

Doppler Dimming Cartoons

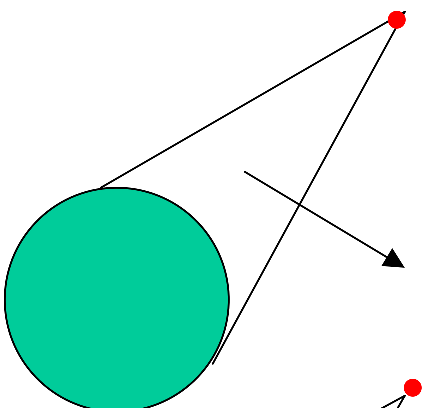


Scattering OVI, no outflow

incoming OVI radiation

Wavelength of exciting radiation

$\lambda = \lambda_0$

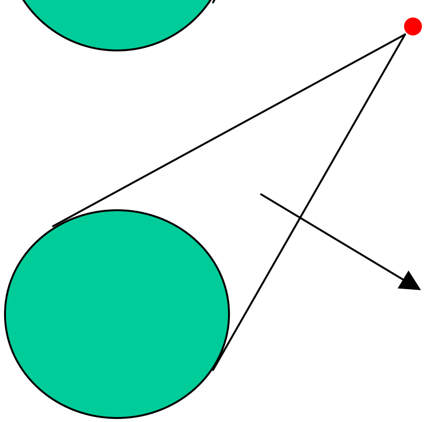


Scattering OVI, outflow = v

incoming OVI radiation

Wavelength of exciting radiation

$(\lambda - \lambda_0)/\lambda_0 = v/c$



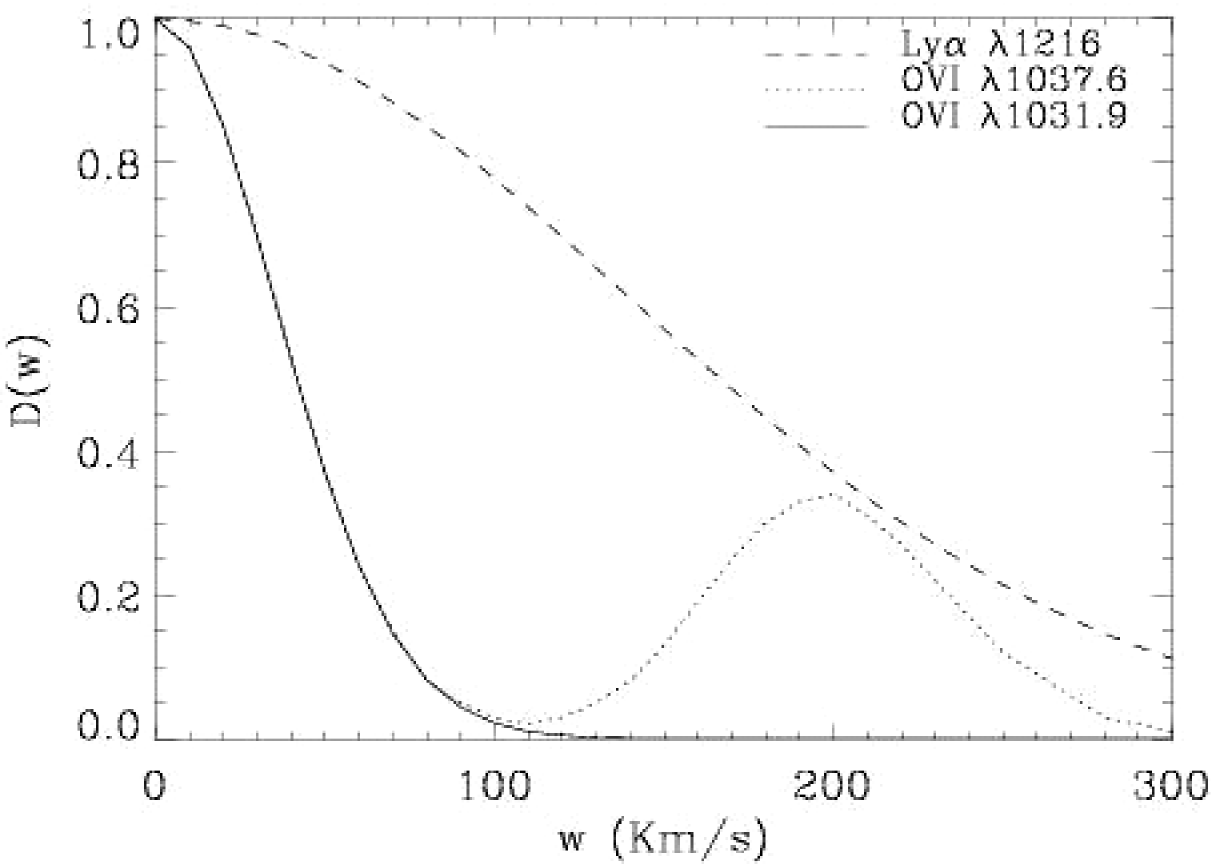
Scattering OVI, outflow = V, Larger than v

incoming OVI radiation

Wavelength of exciting radiation

$(\lambda_{CII} - \lambda_0)/\lambda_0 = V/c$

Doppler dimming in H Ly alpha and OVI doublet lines

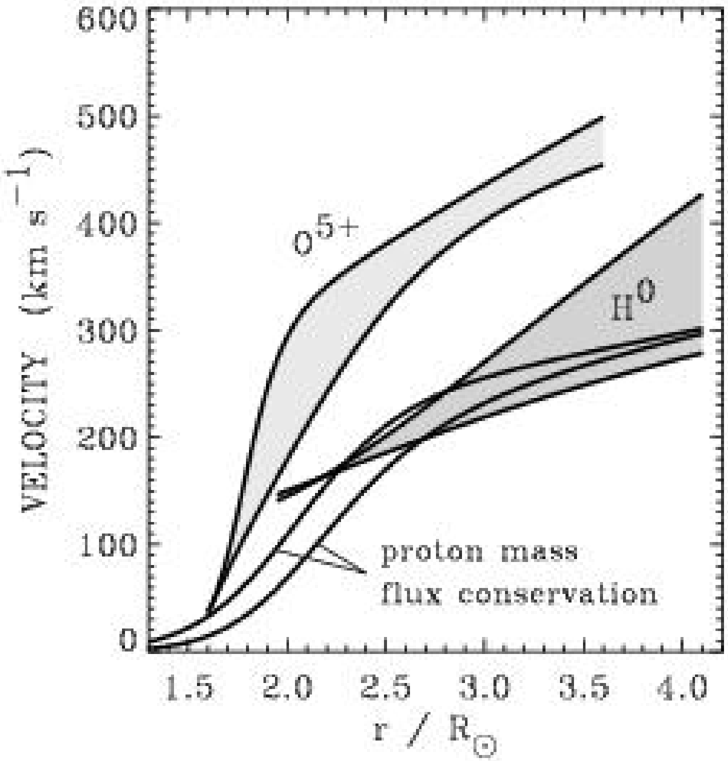


How to build a model of the plasma outflow speed from UV observations

- Starting from
  - UVCS data: H, OVI line intensities and widths
- Knowing
  - coronal densities, electron temperatures, disk intensities, temperatures along and across the magnetic field, the oxygen abundance
- H and OVI line intensities can be reproduced by assuming an appropriate plasma outflow speed
- Uncertainties in the input parameters have an impact on the values of the plasma outflow speed

Model of a polar hole at minimum

Plasma accelerates over
the first few solar radii!



Heavy ions
move faster than
protons!

(Cranmer et al., 1999)

References: models of coronal outflow

- Cranmer, Kohl, Noci et al.: ApJ, 511, 481, 1999
- Antonucci, Dodero, Giordano: SP, 197, 115, 2000
- Strachan, Panasyuk, Dobrzycka et al.: JGR, 105, 2345, 2000
- Miralles, Cranmer, Panasyuk et al.: ApJ, 549, 2001
- Zangrilli, Poletto, Romoli et al.: ApJ, 574, 477, 2002

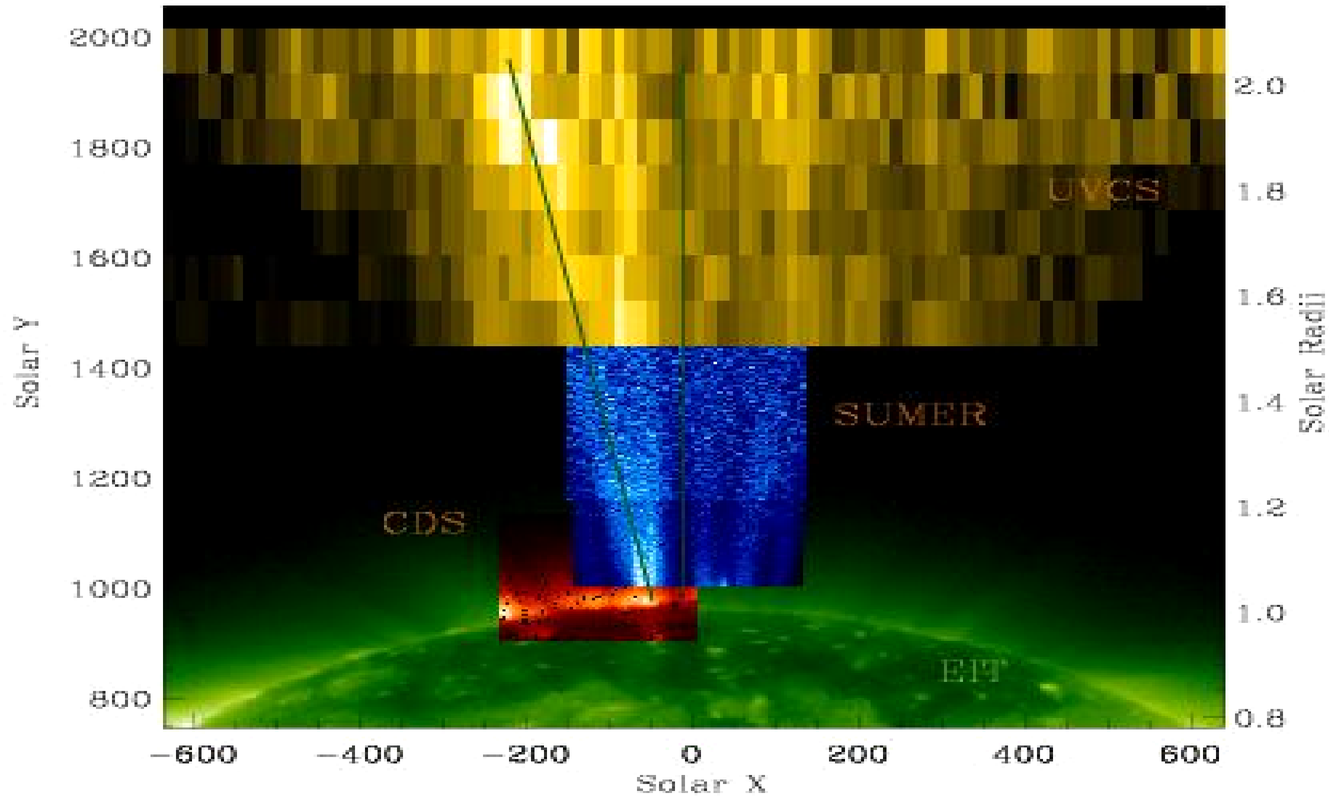
Where does fast wind originate?

- UV lines widths larger in interplumes (Hassler et al., 1997; Wilhelm et al., 1998; Antonucci, 1999; Giordano et al., 1999; Banerjee et al., 2000)
- Line shifts in interplumes = outflows (Wilhelm et al., 2000; Xia et al., 2003 in Ne VIII lines)
- Outflows in interplumes (Patsourakos and Vial, 2000 at 1.05; Giordano et al., 2000 at 1.7 solar radii)

A model for outflows in interplumes

- Teriaca, Poletto, Romoli et al., 2003 (ApJ, 588, 566) built a coronal outflow profile in interplumes from a SUMER+UVCS data set
- They used densities from UVCS WL + LASCO and from literature (below 1.5 R_{sun}), electron T profiles in plumes and interplumes from Wilhelm (up to 1.3 R_{sun}), T_{perp} from line widths measured over their own data set, disk intensities from SOLSTICE and SUMER, an *a priori* oxygen abundance, left T_{par} as a free parameter and found

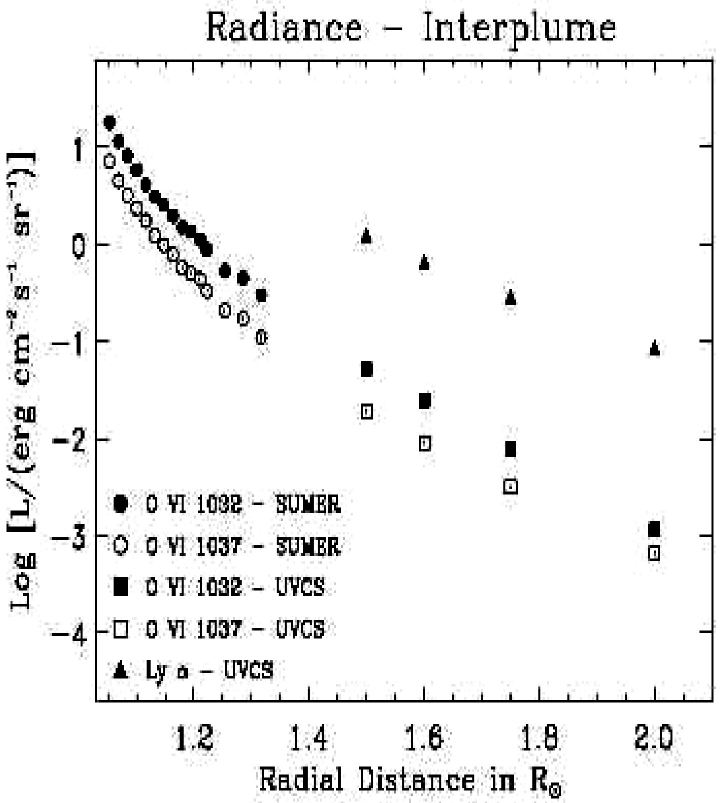
  the outflow vs. altitude profile in interplumes
- Then, assuming a static plume to be imbedded in the interplume ambient, they were able to reproduce the measured values of plume line intensities

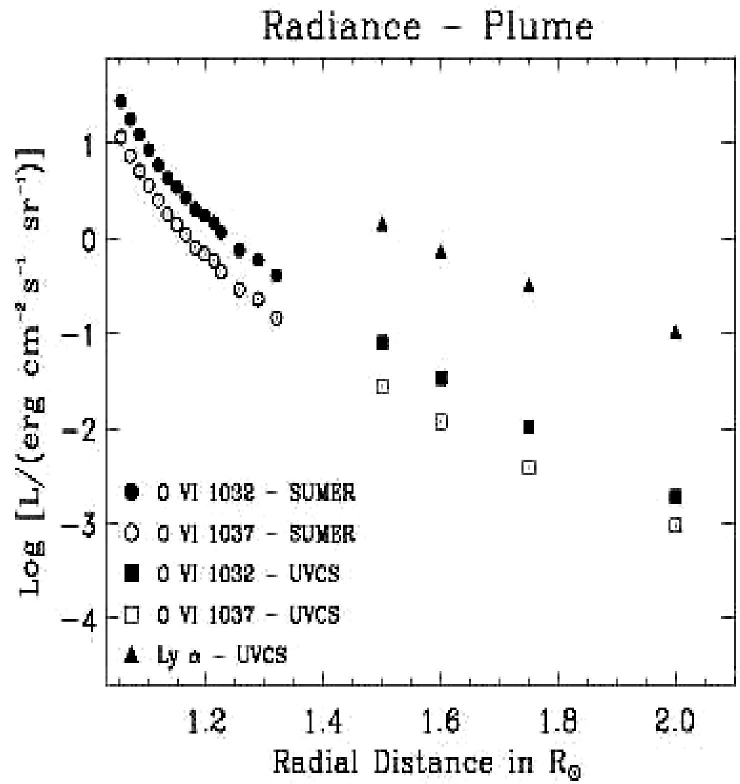


North polar coronal hole, June 3, 1996
EIT Fe XII 195 A, CDS Mg IX 368 A,
SUMER UVCS OVI 1032 A

(Teriaca et al, 2003)

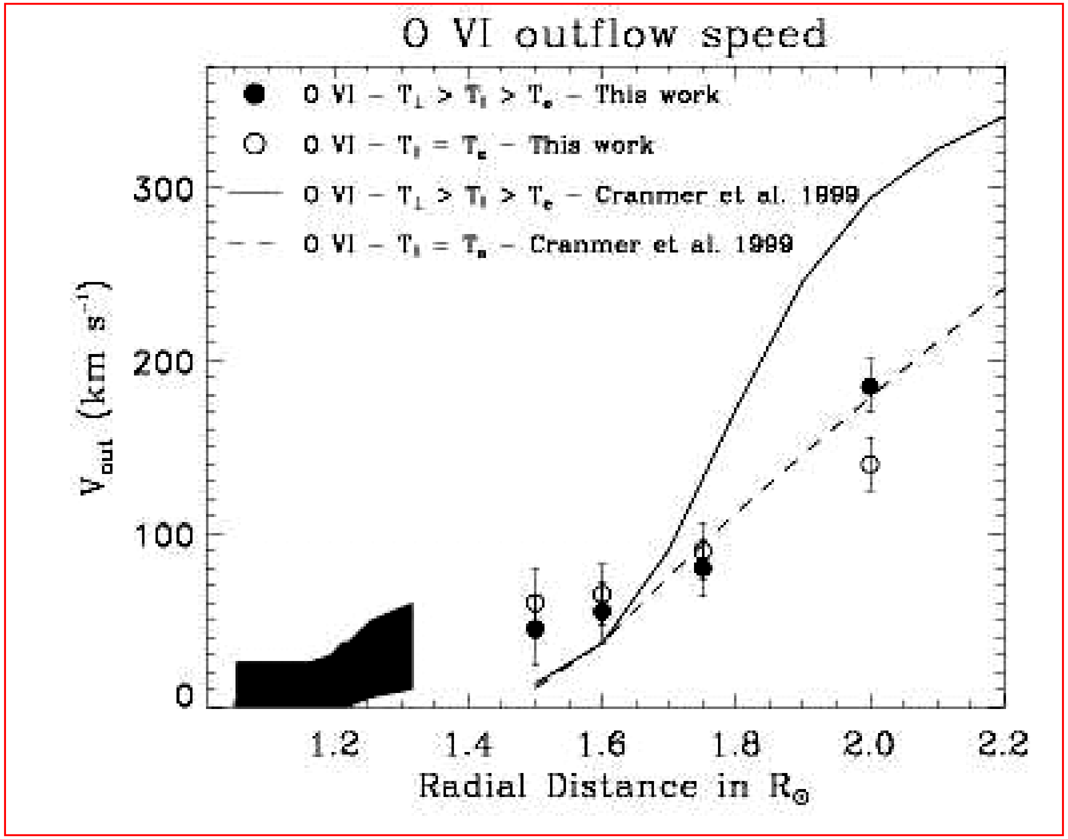
SUMER + UVCS Hydrogen and OVI doublet line radiances in plumes and interplumes





(Teriaca et al., 2003)

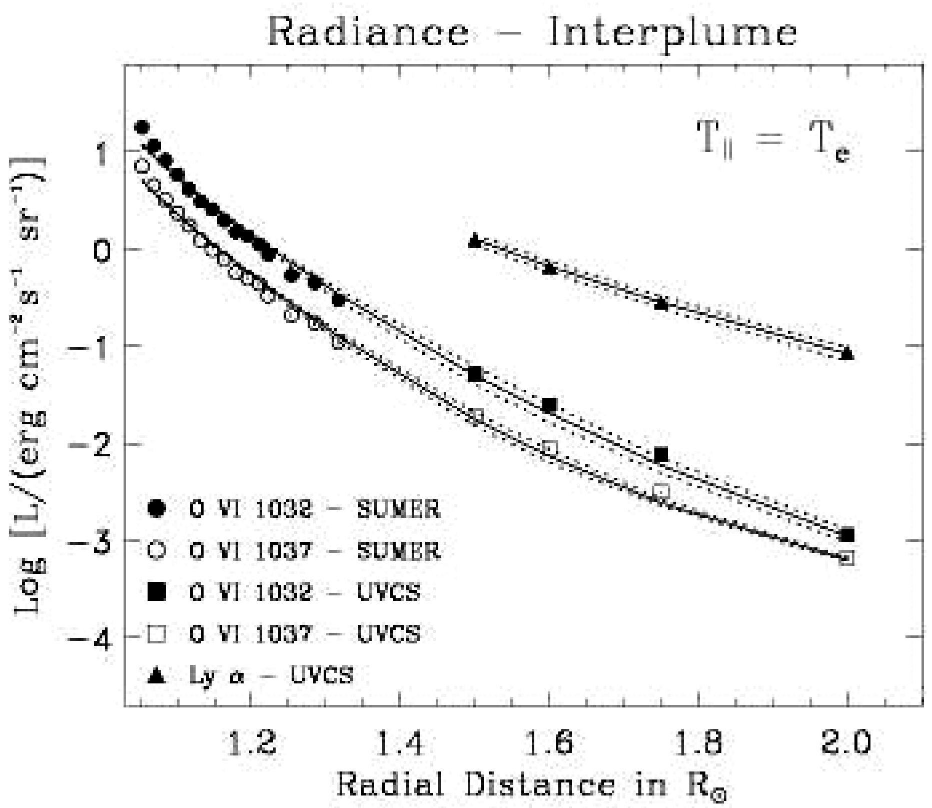
OVI outflow speed in interplume lanes



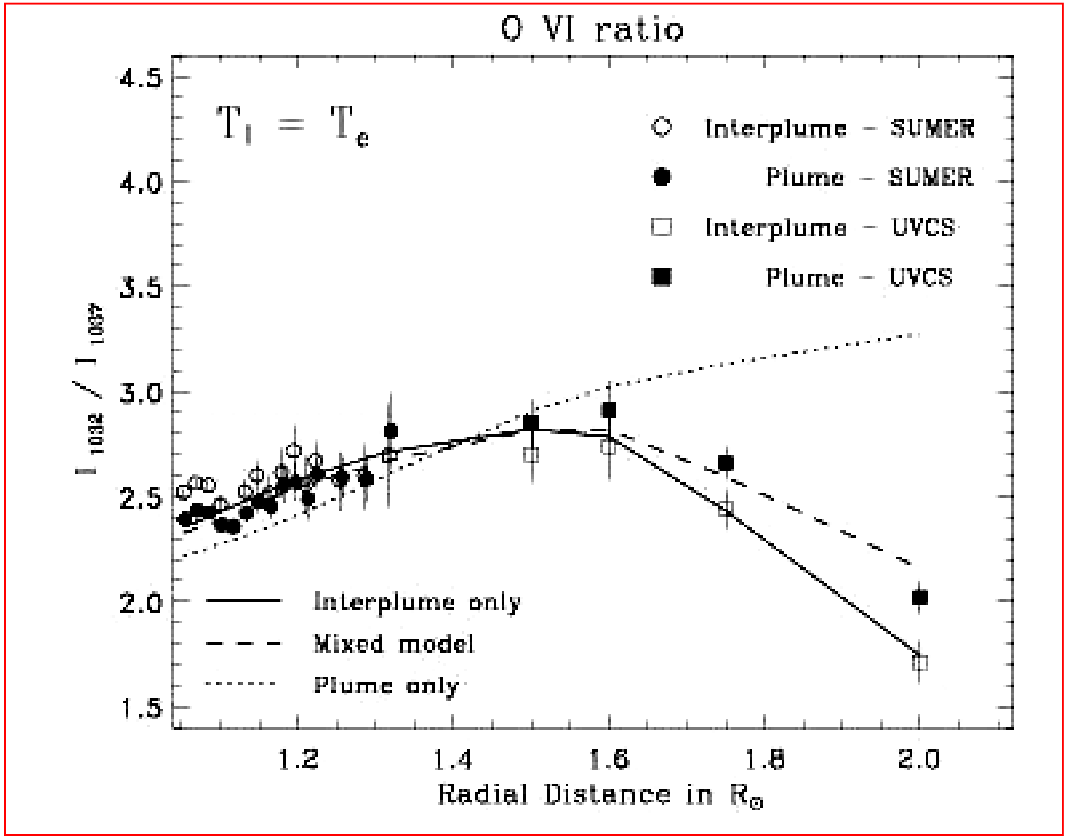
Shaded area: outflows compatible with SUMER data

Heavy ion acceleration starts at altitudes lower than previously anticipated!

Model solution for interplume in the anisotropic case



Plume model: anisotropic case



Dotted line: plume extending over the whole LOS

(Teriaca et al., 2003)

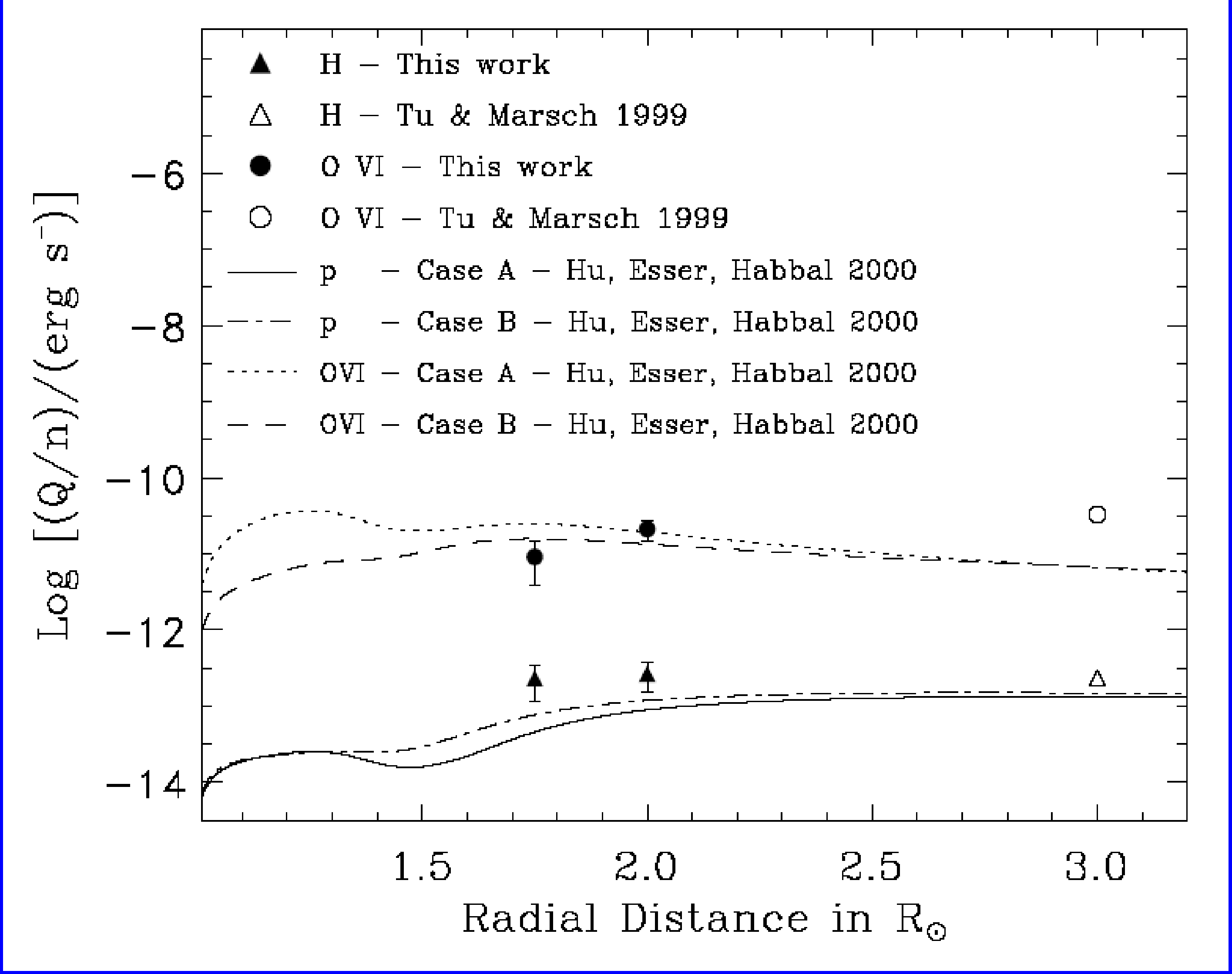
Coronal Heating rate below 2 R_{sun}

- Any heating process should start below 2Rsun!
- Neglecting Coulomb collision terms (R lower than 1.7 R_{sun}) we can use a simplified energy equation to estimate the heating rate per particle from the measured line widths and the outflows derived from the model

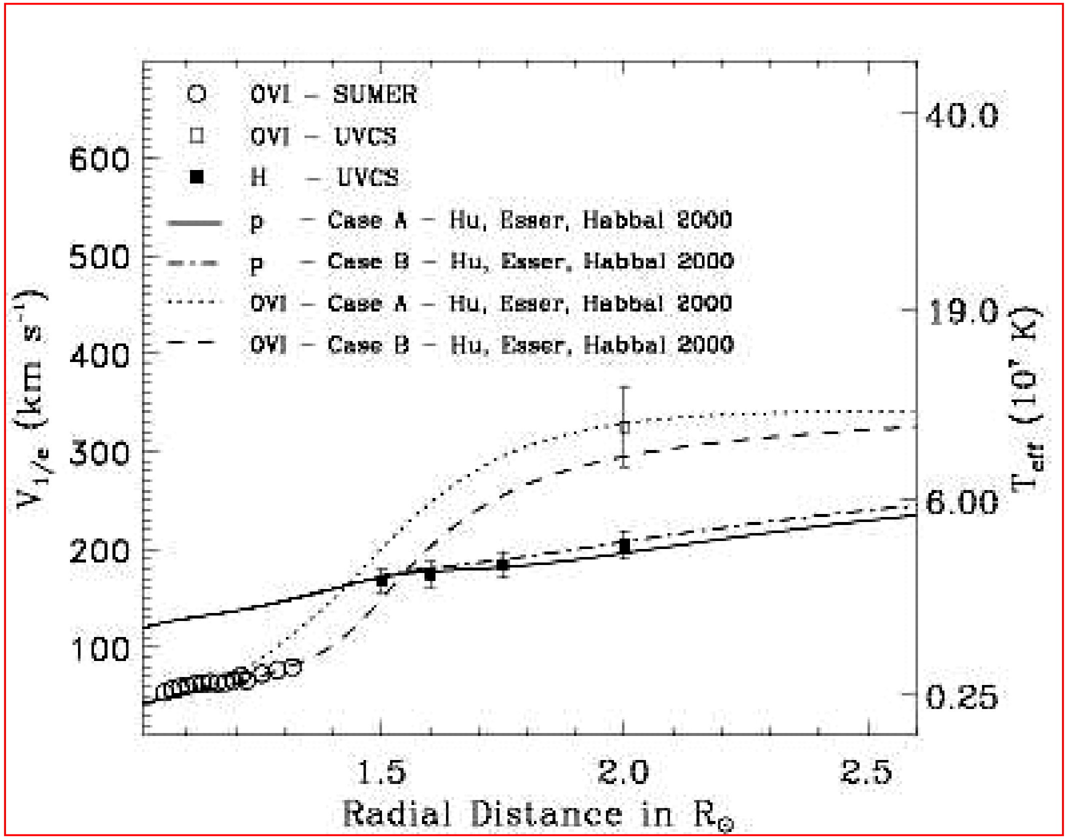
$$Q = V_{out} \left(d\, w^2 / d\, R + 2\, w^2 / R \right)$$

where w is the 1/e line width.

OVI and protons heating rates



(Teriaca et al., 2003)

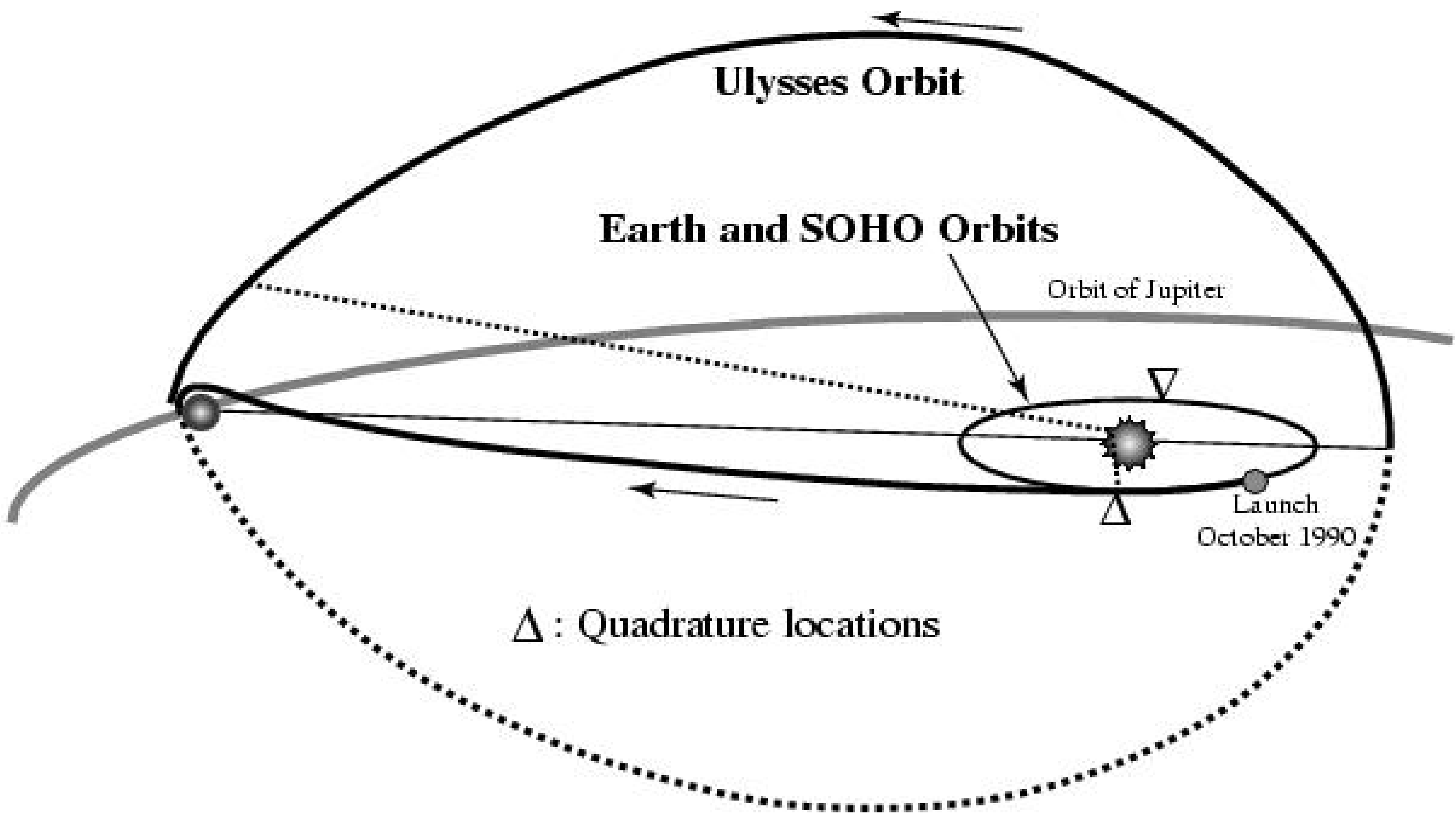


OVI – SUMER
OVI – UVCS
H – UVCS
p – Case A – Hu, Esser, Habbal 2000
p – Case B – Hu, Esser, Habbal 2000
OVI – Case A – Hu, Esser, Habbal 2000
OVI – Case B – Hu, Esser, Habbal 2000
V1/e (km s-1)
600
500
400
300
200
100
40.0
19.0
6.00
0.25
Teff (10^7 K)
1.5
2.0
2.5
Radial Distance in R⊙

Origin and acceleration of slow wind

- Which is the source of the slow wind variability?
- Where does the fast/slow wind transition initiate?
  - Can we trace it back to lower coronal levels or does it set in at larger heliocentric distances?
- Which are the sources of the slow wind streams?
  - Abundance variations can help us establish a connection between coronal structures and wind originating from these structures?

SOHO-Sun-Ulysses quadratures



Fall ’98 Quadrature observations

A typical

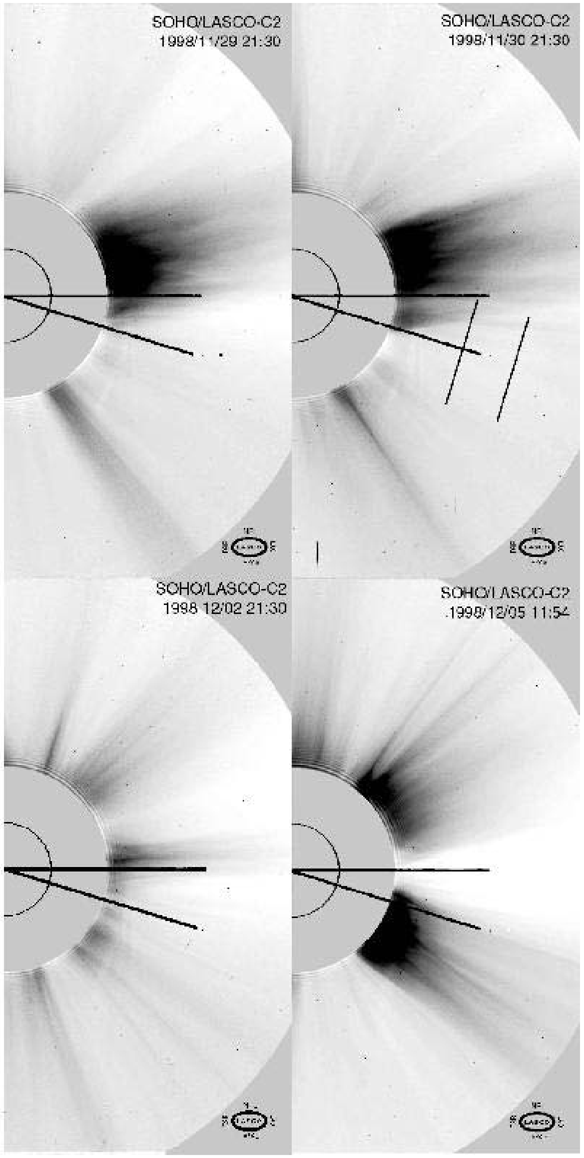
setting

of the UVCS

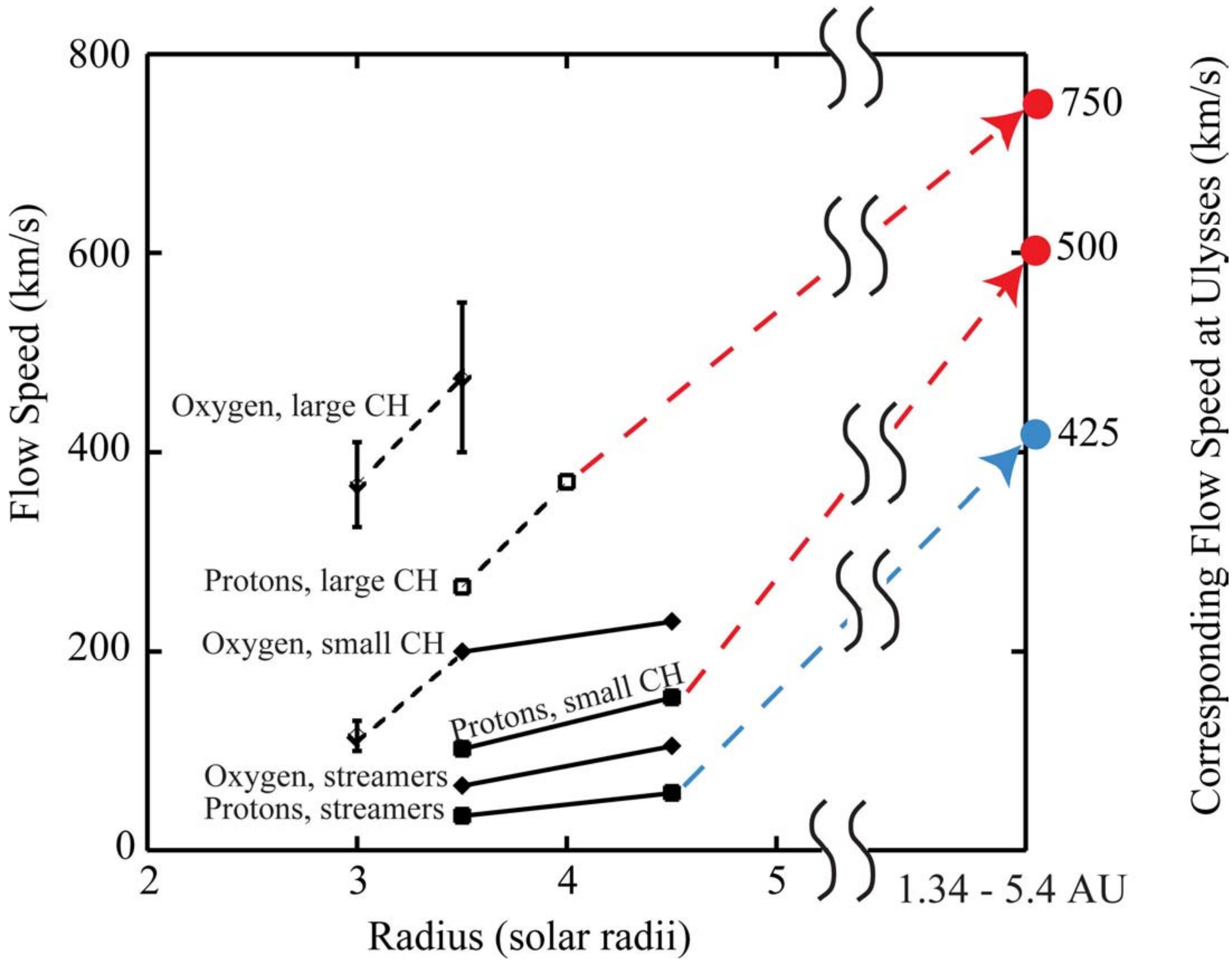
slit

for quadrature

observations



Flow speeds of fast and slow wind

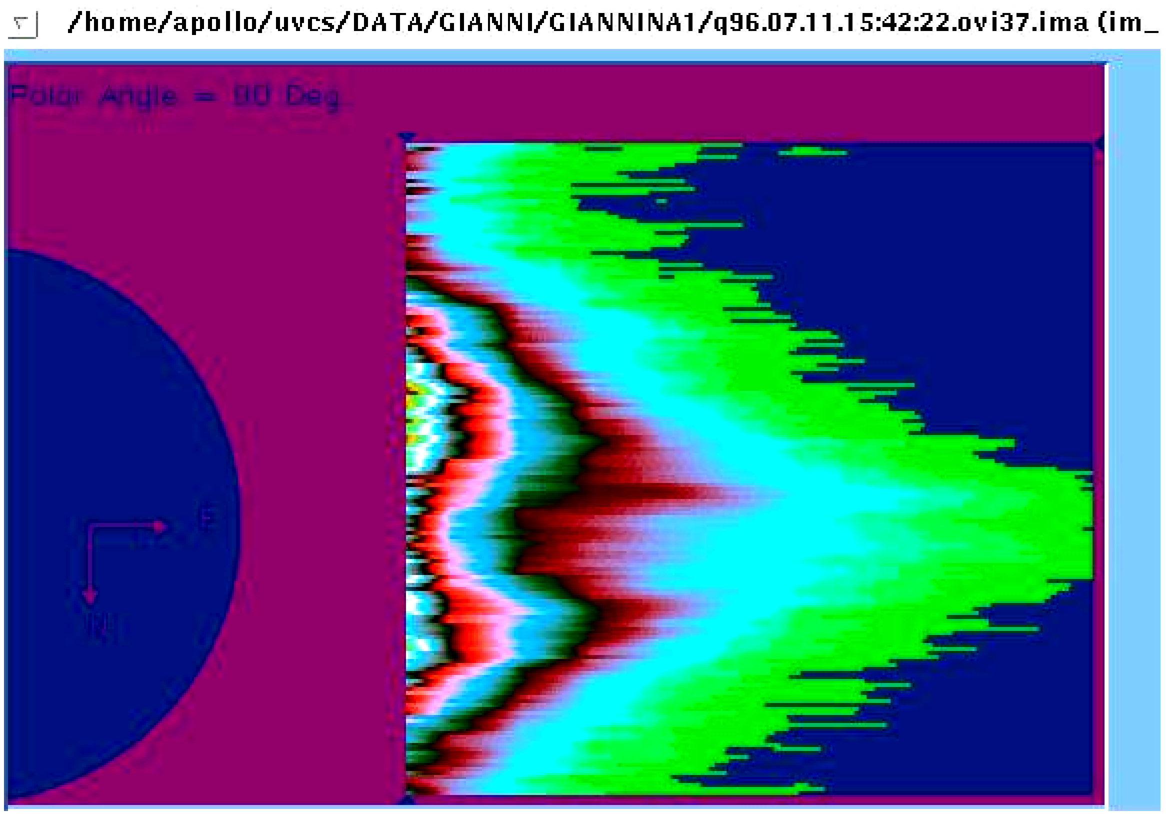


(Poletto, Suess et al., JGR, 107, 2002)

Slow wind acceleration: results from fall 1998 quadrature campaign

- Wind emanating from low latitude holes faster than wind from streamer regions: slow wind variability?
- Heavy ions always faster than protons
- Wind from low latitude holes accelerates over a more extended distance range than polar wind
- Wind from streamer regions accelerates over a more extended interval than wind from low latitude holes
- The slower the outflow speed the wider the acceleration region

STREAMER IMAGE – OVI 1037 line



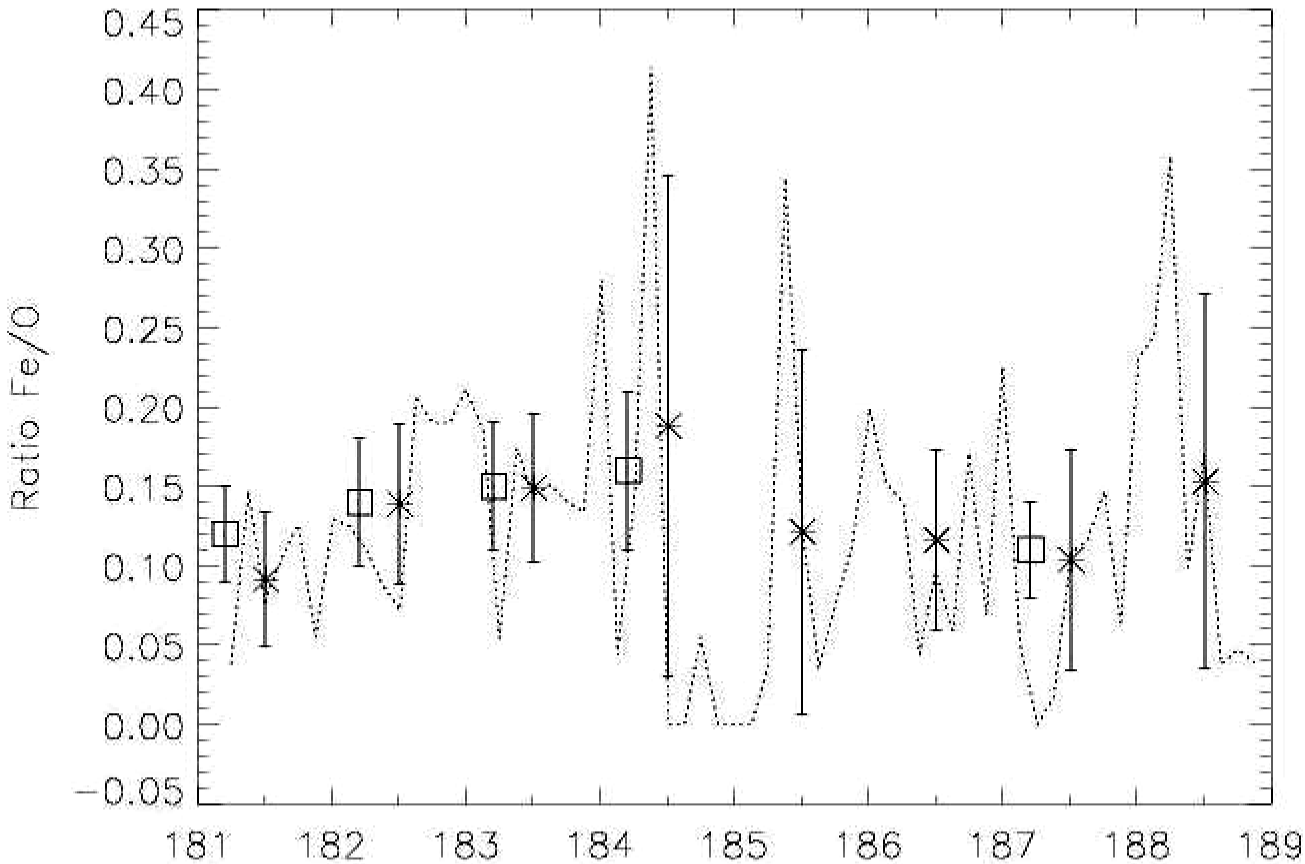
Sources of low latitude streamer wind

- UVCS revealed differences in the OVI intensity distribution across streamers:
  - Difference in elemental abundances?
  - Theoretical works predict streamer legs to be sources of slow wind (see, e.g., Ofman, GRL, 27, 2885, 2000)
- Look for correlation between Fe/O in streamers and solar wind emanating from these structures as a means to to identify the site where slow wind originates

Coronal vs. *in situ* Fe/O

UVCS date	Ulysses date	(Fe/O) Corona	(Fe/O) SWICS	Flow speed
11/VI/00	29/VI/00	0.12 (0.03)	0.09	365 km/s
12/VI/00	30/VI/00	0.14(0.04)	0.14	352
13/VI/00	1/VII/00	0.15(0.04)	0.15	339
14/VI/00	2/VII/00	0.16(0.05)	0.19	333
17/VI/00	5/VII/00	0.11(0.03)	0.10	309

Fe/O in the corona and solar wind

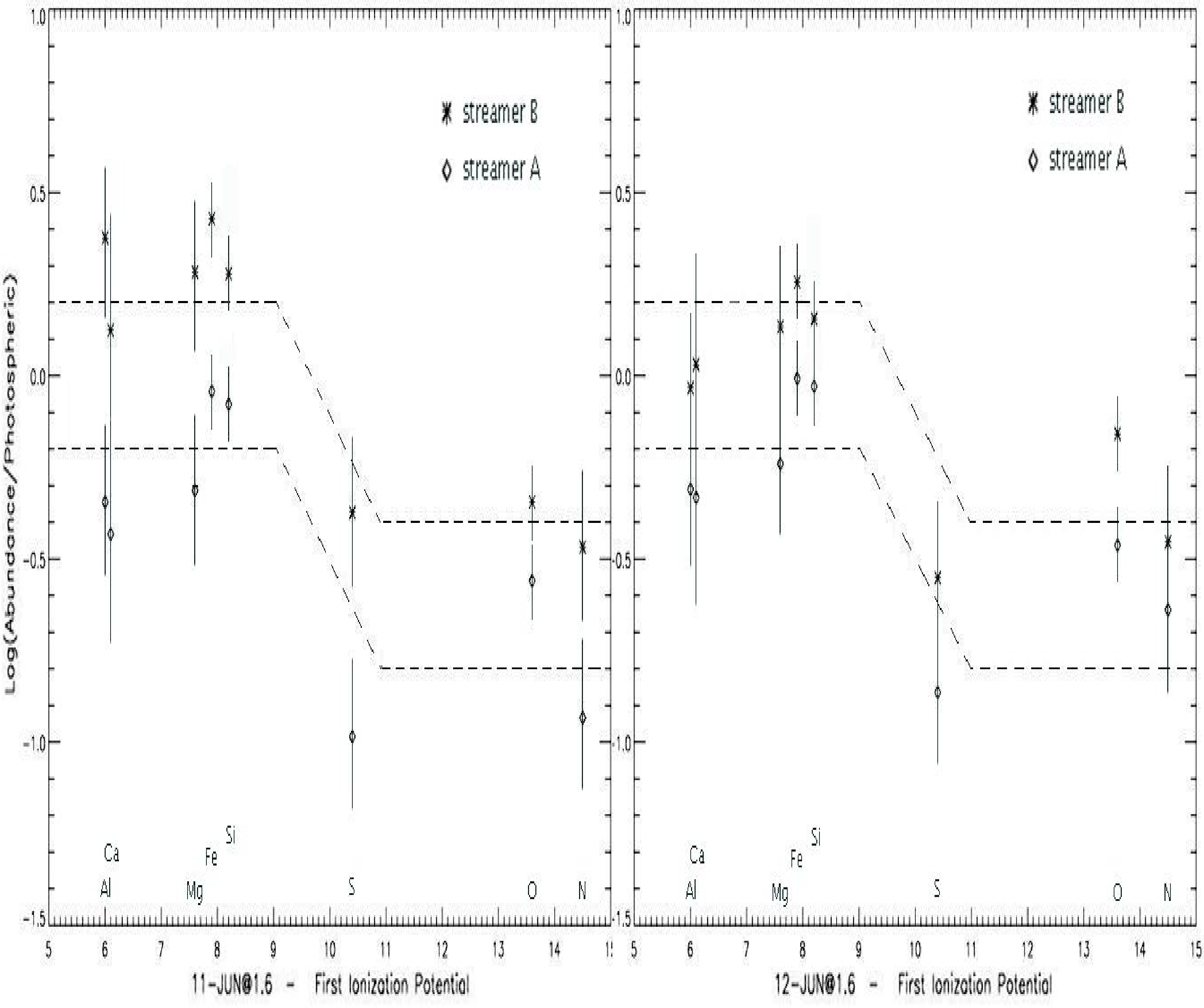


Dotted: 3 hours average from SWICS
Asterisks: daily average from SWICS
Squares: coronal (UVCS) values

(Bemporad, Poletto, Suess, 2003)

Conclusions

- Polar fast wind appears to originate in interplume areas
- Slow wind accelerates over a wider distance range than fast wind does
- Part of the slow wind variability may be ascribed to a different site of origin of the wind
- Absolute element abundances, rather than abundance ratios, are probably more reliable indicators of the slow wind sources


streamer B
streamer A
Log(Abundance/Photospheric)
1.0
0.5
0.0
-0.5
-1.0
-1.5
Ca
Al
Mg
Fe
Si
S
O
N
5
6
7
8
9
10
11
12
13
14
15
11-JUN@1.6 - First Ionization Potential
12-JUN@1.6 - First Ionization Potential